Miller, James H.; Zutter, Bruce R.; Zedaker, Shepard M. [and others]. 1991. A Regional Study on the Influence of Woody and Herbaceous Competition on Early Loblolly Pine Growth. Southern Journal of Applied Forestry 15(1991):169-179.

A Regional Study on the Influence of Woody and Herbaceous Competition on Early Loblolly Pine Growth[1]

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ABSTRACT. A common study design has been installed at 14 locations Southwide to track the growth of loblolly pine established with four different competition control treatments: (a) no control, (b) woody control, (c) herbaceous control, and (d) total control after site preparation. This region-wide investigation is the Competition Omission Monitoring Project (COMP). During the first 5 years, the general pine response by treatment has been greater growth in height, diameter, and volume index as follows: total control > herbaceous control > woody control > no control. Generally, diameter growth was more responsive than height to vegetation control treatments. On 13 plantation study sites, pine volume after 5 years with total control averaged about fourfold more than with no control. Volume was increased by an average of 67% with woody control, while herbaceous control increased volume by 171%, showing the greater average influence of herbaceous competition during the initial 5 years. The magnitude of growth reductions by competitors varied by site and intensity.

South. J. Appl. For. 15(4):169–179.

Numerous studies have been established in the past 20 years examining the influence of herbaceous and woody vegetation on the growth of loblolly pine (*Pinus taeda* L.), yet few can be compared. Research in forest vegetation management has been plagued by the absence of a logical context wherein crop growth response at various sites can be mutually compared to levels of competition. To develop such a standard response framework for loblolly pine, a group of investigators established a region-wide study that continues to examine growth relative to four competition situations (Miller et al. 1987). The four situations are the corner extremes of a response surface that encompasses most competition conditions common to young plantations. Pine growth is the dependent variable, and woody and herbaceous competition are the two independent variables (Figure 1).

The four competition situations are: (a) no control with a mixture of woody and herbaceous competitors, (b) woody control leaving herbaceous species, (c) herbaceous control leaving woody species, and (d) total competition control. In this simplified framework, arborescent hardwoods and nonarborescent shrubs are combined as woody competition; forbs, grasses, vines, and semiwoody vegetation comprise the herbaceous component. Of the 14 study locations, the one at Crossett, Arkansas, is studying natural regeneration, and the rest are studying planted plantations. The Crossett study results are presented in the article on p. 179.

The influence of herbaceous competition on early pine growth has been increasingly investigated in the South for the past 10 years. Creighton et al. (1987) summa-

[1] This study was funded in part by the members of the Auburn University Silvicultural Herbicide Cooperative. The cooperators in this study include the authors and Lee Atkins, DuPont; Edward Daly and Charles Hollis, International Paper Company; William S. Garbett, Union Camp; W.W. Pope and Scott Millburn, Potlatch Corporation; Rick Applegate and C.W. Mueller, American Packaging Corporation; Sam Campbell and Mickey Rachel, Scott Paper Company; Don McMahone, Williamette Industries; and James A. McGriff, Georgia-Pacific Corporation. Study establishment was greatly assisted by Steven A. Knowe, Oregon State University, and Kenneth Xydias, Resource Management Services. The continued contributions of Erwin Chambliss and Juanita Crawford, USFS, have been invaluable to this effort.

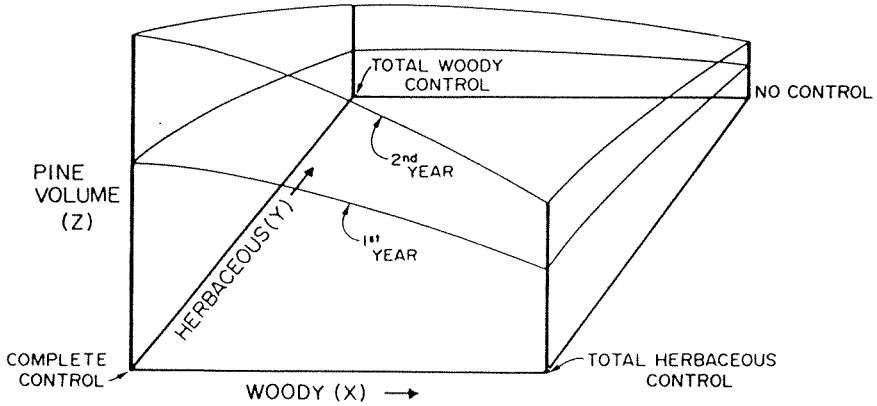

Figure 1. Conceptual response surface of woody and herbaceous competition effects on pine volume.

Reprinted from the *Southern Journal of Applied Forestry*, Vol. 15, No. 4, November 1991

rized results from 16 locations where completeness and duration of herbaceous control are under study. Significant early growth gains were reported where loblolly pines received 1 or 2 years of herbaceous control vs. none. Both pine height and diameter were greater after 2–7 years on all sites with herbaceous control, while survival was significantly increased on 42% of the locations studying loblolly pine. Over half the sites had significantly larger trees with 2 years vs. 1 year of control, but the increase was measurably less with the second-year treatment.

McKee and Wilhite (1988) also found that first-year weed control yielded greater loblolly pine volume than second-year control when using narrow control bands on poorly drained sites in South Carolina. Contrary to this, Bacon and Zedaker (1987) reported on a study in the Virginia Piedmont where herbaceous control in the second year (vs. first or third) when combined with woody control treatments yielded significantly more volume, 37% more (vs. 24% or 23% respectively) after 3 years. Clason (1978) found that herbaceous control in the seventh year of a loblolly pine plantation in northern Louisiana did not significantly enhance growth. Thus, it appears that herbaceous control is most effective in the first 1 or 2 years to maximize initial growth gains and at times to increase survival and promote uniform stocking and growth. Recent research also suggests that of the herbaceous components, the most competitive to young loblolly pine are the rhizomatous and cool-season grasses compared to tufted (bunch) grasses and forbs (Morris et al. 1989, Smith 1989).

Treatments for woody control have been applied operationally in the South for about 40 years. Several studies have more recently quantified the significant growth increase of loblolly pine that results from woody plant control (Langdon and Trousdell 1974, Clason 1978, Cain and Mann 1980, Haywood 1986, Tiarks and Haywood 1986, Miller 1987). These scattered reports have not permitted a generalized interpretation of response across physiographic provinces, except to conclude that both short- and long-term growth increases do occur after early woody control treatments. There is also an indication that some level of control, less than complete woody control, may provide optimum pine growth on some sites, especially when combined with herbaceous control treatments (Bacon and Zedaker 1987).

Objectives of the COMP investigation are: (1) to establish a framework of growth response for loblolly pine relative to four competition regimes on major soil types across the region, (2) to compare the relative importance of herbaceous vs. woody competition as they affect the early and long-term growth of loblolly pine on a wide range of sites, (3) to identify the major herbaceous and woody competitors and document early succession, and (4) to study the interaction of competition and pine growth on insect and disease infection. The last two objectives will be addressed in other reports from this research group.

METHODS

Study Sites

A common study design was utilized at 13 plantation sites on four physiographic provinces—the Lower, Middle, and Hiliy Coastal Plains and Piedmont—in Louisiana, Arkansas, Mississippi, Tennessee, Alabama, Georgia, and Virginia (Table 1 and Figure 2). Prior to plot establishment, pine plantations or mixed pine-hardwood stands were harvested in late-1982 or 1983. Site preparation was by roller-drum chopping and prescribed burning at ten study locations. A shear, pile, and burn method was used at Counce (TN), which resulted in some topsoil removal and displacement into the windrows. A complete harvest of fuelwood and pine was used at Atmore (AL), and the lower coastal plain site near Pembroke (GA) was rebedded after a wildfire destroyed a young plantation.

Plot Layout

Four blocks of four plots each were established at 11 of the 13 locations using a factorial, randomized complete-block design. Blocking by slope and/or vegetation attempted to encompass the varied sites found across the terrain at each location to expand the scope of the study. At Pembroke (GA) a fifth block was included, and at Bainbridge (GA) a completely randomized design was used. Treatment plots were generally 0.25 ac in size, and interior measurement plots were 0.09 ac. Precisely measured planting spots on a 9 × 9 ft spacing characterized all but the operationally planted sites at Pembroke (GA) and Arcadia (LA) (Table 1). This spacing resulted in 538 trees per acre and 49 measurement pines in the interior plots, with two border rows surrounding measurement plots.

At most sites, two regraded 1-0 loblolly pine seedlings were planted at each spot, 10–12 in. apart. Either genetically improved or Livingston Parish seedlings were used. After the first growing season, double-planted seedlings were thinned to one per spot using randomly generated codes so as to maintain the original population characteristics. Double planting was used to minimize the variation attributable to survival and the resulting long-term variation that occurs with unequal stocking. Only single seedlings were planted at Pembroke (GA), Arcadia (LA), and Liberty (MS), where adequate survival resulted in stocking levels comparable to the other locations. All measurement trees were permanently tagged. Volunteer pines were repeatedly removed from all locations except at Appomattox (VA), where Virginia pine (*Pinus virginiani* Mill.) was left on woody competition plots since it is considered a common woody competitor in this area.

Establishment of Competition Situations

Four treatments, or competition situations, were established and maintained as follows:

Table 1. Description of study sites.

Location by province (location number)	Cooperator	Soil series	Previous stand	Harvest	Site preparation	Regeneration
Lower Coastal Plain						
Pembroke, GA (1)	Union Camp	Mascotte Pelham	6-year-old plantation burned by wildfire	N/A	rebedded 1983	machine planted 7 × 11 ft Winter 1983–84
Middle Coastal Plain						
Bainbridge, GA (2)	International Paper	Orangeburg Esto	mixed loblolly/ shortleaf pine-hardwood	Winter 1982–83	KG blade, chop & burn	hand planted 9 × 9 ft Jan 1984
Liberty, MS (3)	Dupont & Georgia-Pacific	Saffell	mixed loblolly/ shortleaf pine-hardwood	April 1983	chop Summer 1983	hand planted 9 × 9 ft Feb 1984
Atmore, AL (4)	Scott Paper	Orangeburg	slash pine plantation	Sept 1983	whole-tree chipped at harvest	hand planted 9 × 9 ft April 1984
Liverpool, LA (5)	USFS & Cavenham	Tangi	Loblolly pine	Winter–Summer 1983	chop & burn Summer 1983	hand planted 9 × 9 ft Feb 1984
Jena, LA (6)	International Paper	Ruston	mixed pine-hardwood	Fall 1983	chop & burn Summer 1983	hand planted 9 × 9 ft Jan 1984
Arcadia, LA (7)	La. Tech. U. & Williamette	Boswell Bowie Sacul Beauregard	natural loblolly pine	1983	chop & burn Summer 1984	machine planted 7 × 10 ft Jan 1985
Hilly Coastal Plain						
Tallassee, AL (8)	Auburn Univ.	Cowarts	Loblolly pine plantation	Spring 1983	chop & burn late Spring–early Summer 1983	hand planted 9 × 9 ft Jan 1984
Warren, AR (9)	Potlatch	Saffell Stough	Loblolly/shortleaf pine chip-and-saw	June 1983	chop & burn Summer 1983	hand planted 9 × 9 ft Feb 1984
Counce, TN (10)	Packaging Corp.	Silerton	natural mixed pine-hardwood	Winter 1982–83	shear, pile & burn windrows Summer/Fall 1983	hand planted 9 × 9 ft March 1984
Piedmont						
Camp Hill, AL (11)	USFS	Cecil Pacolet	natural mixed pine-hardwood	Spring 1983	chop Spring 1983	hand planted 9 × 9 ft Jan 1984
Monticello, GA (12)	USFS	Davidson	natural mixed pine-hardwood	Oct 1982	chop & burn Summer 1983	hand planted 9 × 9 ft Feb 1984
Appomattox, VA (13)	VPI & SU	Cecil Cullen Iredell	natural mixed pine-hardwood	June 1983	chop & burn Summer 1983	hand planted 9 × 9 ft Feb 1984

1. *No control resulting in mixed herbaceous-woody competition.* After initial site preparation, no further treatments were applied except for vine control and injections of scattered residual hardwoods. Vines were treated with shielded directed sprays of glyphosate (Roundup) and triclopyr (Garlon) or wick applications of triclopyr. Scattered large hardwoods not removed during site preparation were injected with triclopyr at some locations.
2. *Woody control only resulting in herbaceous competition.* Both foliar and basal sprays, as well as basal wipes, were used to control hardwoods and shrubs during the first 5 years. A single preplant and multiple post-plant applications per year were made usually with directed sprays of glyphosate, triclopyr, and picloram (Tordon), or basal wipes of triclopyr and diesel fuel. After planting, only herbicides with no soil activity were used to minimize any potential damage to herbaceous weeds and measurement pines.
3. *Herbaceous control only resulting in woody competition.* Preemergent applications of sulfometuron (Oust) at 3–6 oz/ac were applied annually for the first 4 years to control forbs and annual grasses. The most efficacious rate, having the least pine toxicity, was determined through screening trials on nearby sites at most locations during the year prior to establishment. After the first year, either glyphosate at 18 oz/ac or oxyfluorfen (Goal) at 0.6 gal/ac were commonly added to the tank mix with sulfometuron. One to five times during a growing season, shielded directed sprays of glyphosate (2% solution) were applied to resistant forbs, perennial grasses, and vines. At Bainbridge, sethoxydim (Poast) was broadcast sprayed for grass control in the second year.
4. *Total control resulting in elimination of all competition.* A combination of the treatments discussed above were used to yield bare ground conditions.

The duration of herbaceous control was for 4 years, although control persisted during the fifth

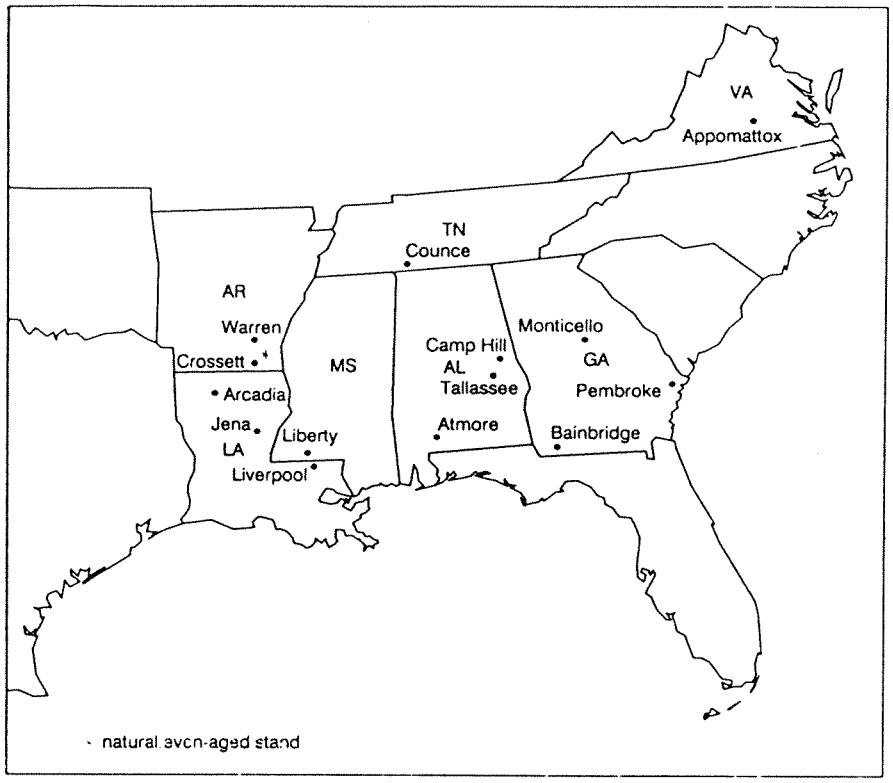

Figure 2. COMP study locations.

year as well. Woody control is to be maintained for a rotation. Thus, not only were the extremes of completeness encompassed but also the extremes of duration. Minimal crop pine damage was observed with these treatments.

Measurements and Analyses

Pines were annually measured for total height and diameters at groundline (GLD), at a 6-in. height (D6), and at breast height (dbh). D6 measurements commenced after the first year and dbh measurements after the second year. A tree volume index for years 1 and 2 was estimated using a conical projection with GLD and height. For years 3–5, tree volume was estimated by summing volumes of stem sections from GLD to D6, D6 to dbh, and dbh to total height. Smalian's formula was used from GLD to D6 and from D6 to dbh (Husch et al. 1979), and a conical projection from dbh to total height. Where total height was less than dbh, a conical projection from D6 to total height was used for the topmost section. Tree volume indices were expanded to an acre estimate by summing all surviving trees and multiplying by the appropriate expansion factor for the measurement plot.

Annually in September, counts were made of nonarborescent woody stems and estimates of herbaceous cover by components (grasses and sedges, forbs, vines, and semiwoody's). Counts of nonarborescent woody rootstocks were recorded on three systematically located sample plots per measurement plot that were located between pine rows. Sample plots were 9 × 18 ft where pines were planted on a 9 × 9 ft spacing and of a similar area at the two operationally planted locations. Ocular estimates of herbaceous cover were made on 9 × 9 ft halves of each sample plot—six estimates per measurement plot. After the fifth growing season, all arborescent rootstocks within interior measurement plots that exceeded 4.5 ft tall were measured for stem height and dbh by species.

Pine and competition data were analyzed separately by location using the appropriate analysis of variance with arcsine squareroot transformations for percent values. The influence of woody and herbaceous competition on early development was examined using orthogonal contrasts and linear regression analysis. A 0.05 level of probability for a Type I error was considered significant.

RESULTS AND DISCUSSION

Competition Levels

Hardwood and shrub competition, the woody component, varied greatly among study locations (Tables 2 and 3). In the fifth year, arborescent basal area on no control check plots averaged 3.8 ft^2/ac; exceeding 4.7 ft^2/ac at five locations, ranging from 3–4 ft^2/ac at four locations, and less than 1 ft^2/ac at four sites. The density of arborescent stems on no control plots averaged 1065 rootstocks/ac, ranging from 159–2406 rootstocks/ac. On woody control only plots, arborescent competition was greatly reduced, with less than 0.5 ft^2/ac of basal area at all locations. Orthogonal contrasts for woody control were significant (<0.05) at all locations for both basal area and rootstock numbers (Table 3), indicating significant reductions with control treatments.

Eight locations had more than 7 ft^2/ac of hardwood basal area in only 5 years with herbaceous control. With herbaceous control only, the basal area of arborescent hardwoods increased from 1.8–6 times compared to levels on no controls, except at Liberty (MS) and Monticello (GA), where no increases occurred. Basal area averaged 7.6 ft^2/ac with herb-control (1.2–17.1 ft^2/ac) compared to the 3.8 ft^2/ac with no control (0.2–9.7 ft^2/ac). The number of rootstocks averaged only 10% more on herb-control only plots vs. no control—1,187 vs. 1,065 rootstocks/ac. Therefore, the doubling of hardwood basal area occurred on about the same number of rootstocks per acre, indicating the response in hardwood size to herbaceous control.

Greater than 2,000 nonarborescent woody rootstocks per acre occurred on no-control plots in the fifth year at all locations except

Table 2. Woody competition in the fifth year and the average herbaceous cover in September for the first 5 years.

Vegetation control	LCP	Middle Coastal Plain						Hilly Coastal Plain			Piedmont		
	Pembroke GA (1)	Bainbridge GA (2)	Liberty MS (3)	Atmore AL (4)	Liverpool LA (5)	Jena LA (6)	Arcadia LA (7)	Tallassee AL (8)	Warren AR (9)	Counce TN (10)	Camp Hill AL (11)	Monticello GA (12)	Appomattox VA (13)
	Arborescent Basal Area (ft^2/ac)												
None	0.4	5.8	9.7	3.2	3.4	0.6	3.1	8.8	0.2	0.7	5.3	3.3	4.7
Woody	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.1
Herb	1.4	10.7	9.6	7.3	10.4	1.9	12.3	17.1	1.2	2.0	14.7	2.2	8.5
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.3
	Arborescent rootstocks (no./ac)												
None	326	1830	2406	664	1114	277	1027	1745	159	439	1827	870	1163
Woody	19	8	0	0	0	25	131	0	0	0	0	107	36
Herb	443	2714	1813	587	1180	302	1335	1704	192	527	2769	392	1476
Total	2	0	0	0	0	0	0	0	0	0	0	52	19
	Nonarborescent woody rootstocks (no./ac)												
None	4893	3944	6789	8537	3496	1143	12433	493	2465	2017	9299	2532	5692
Woody	1109	829	0	269	650	650	1044	0	493	538	1165	134	45
Herb	3062	1479	874	4459	1613	224	1838	201	90	336	5826	964	3563
Total	493	0	0	0	157	0	0	0	0	45	22	67	45
	Average herbaceous cover (%)												
None	70	85	43	75	81	89	85	56	75	78	86	61	42
Woody	90	92	84	87	90	92	88	91	79	81	94	60	52
Herb	20	55	8	7	12	10	13	2	3	7	2	13	17
Total	13	5	1	1	11	12	22	2	3	6	1	11	24

Jena (LA) and Tallassee (AL). They were most abundant at Arcadia (LA) with 12,433 rootstocks/ac, while more than 6,000 rootstocks/ac were growing at Liberty (MS), Atmore (AL), and Camp Hill (AL). Control of nonarborescent woody regrowth was less successful on some sites because of persistent reinvasions of sumac (*Rhus* spp.), but contrasts for nonarborescent woody control were significant for all locations (Tables 2 and 3). Nonarborescent shrubs tended to decrease with herbaceous control, mainly due to shading from the released arborescent component and some selective damage and control by herbicide treatments.

Herbaceous control treatments were effective at all locations, judging from the average herbaceous cover in September for the first 5 years (Table 2) and the significant contrasts at all locations (Table 3). On those plots receiving herbaceous control there was an average of 66% less cover (77% vs. 11%). Greater levels of control were evident in the spring and early summer immediately after broadcast herbicide applications, but regrowth had occurred by September, even with spot spraying during the growing season. Also, species resistant to sulfometuron had increased on some sites early on and in later years were controlled with directed spraying. On woody

Table 3. Contrast probabilities of greater F-statistics associated with means of fifth-year woody competition and average herbaceous cover in September for the first 5 years.

Vegetation control	LCP	Middle Coastal Plain						Hilly Coastal Plain			Piedmont		
	Pembroke GA (1)	Bainbridge GA (2)	Liberty MS (3)	Atmore AL (4)	Liverpool LA (5)	Jena LA (6)	Arcadia LA (7)	Tallassee AL (8)	Warren AR (9)	Counce TN (10)	Camp Hill AL (11)	Monticello GA (12)	Appomattox VA (13)
	Arborescent Basal Area												
Woody (W)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	0.026	<0.001	0.001	<0.001
Herb (H)	0.002	0.171	0.958	<0.001	0.027	0.018	0.002	0.088	0.075	0.251	<0.001	0.370	0.021
W × H	0.002	0.170	0.958	<0.001	0.027	0.016	0.002	0.088	0.075	0.251	<0.001	0.213	0.031
	Arborescent Rootstocks												
Woody	<0.001	0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	0.003	0.001	<0.001	0.001	<0.001
Herb	0.328	0.444	0.351	0.780	0.893	0.999	0.548	0.946	0.713	0.674	0.132	0.039	0.351
W × H	0.197	0.437	0.351	0.780	0.893	0.590	0.157	0.946	0.713	0.674	0.132	0.087	0.303
	Non-Arborescent Rootstocks												
Woody	<0.001	<0.001	0.002	0.001	<0.001	0.015	0.002	0.021	<0.001	0.045	<0.001	<0.001	<0.001
Herb	0.033	<0.001	0.008	0.136	0.016	<0.001	0.005	0.271	<0.001	0.019	0.048	0.014	0.203
W × H	0.255	0.012	0.008	0.185	0.119	0.291	0.015	0.271	0.001	0.153	0.278	0.021	0.203
	Average Herbaceous Cover												
Woody	0.130	0.003	<0.001	0.329	0.105	0.072	0.051	<0.001	0.227	0.365	0.142	0.670	0.062
Herb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W × H	0.008	<0.001	<0.001	0.021	0.032	0.288	0.210	<0.001	0.198	0.117	0.087	0.819	0.670

control only treatments, herbaceous cover averaged 12% more compared to no controls over the first 5 years (83% vs. 71%), with a range from no increase at Monticello (GA) to 41% more cover at Liberty (MS).

Pine Response

Pine density (stocking) levels were not influenced by competition at most locations owing partially to the double planting used at establishment (Table 4). When compared with the no control, density across all sites averaged 3% less with woody control only and 2% less with herbaceous control only, and no difference with total control. At three locations, herbaceous control treatments resulted in significant, but minor, differences in stocking (Table 5). At Liberty (MS) and Jena (LA), herbaceous control treatments (on the herb-control and total-control plots) significantly increased pine density, while at Liverpool (LA) the density was decreased. All locations had greater than 80% of the original planting spots with live trees after 5 years except the woody control plots at Liberty (MS) and Appomattox (VA), which had an average of 70% or 379 trees/ac and 78% or 425 trees/ac, respectively.

Pine height and diameter growth significantly and consistently increased with herbaceous control at every location (Tables 4 and 5). The amount of increase varied by location relative to competition levels and site productivity, but specific trends are evident. The most productive sites were generally on the Middle Coastal Plain, especially following total competition control. Both woody-only and herbaceous-only control treatments increased diameters proportionately greater than heights (Table 6), while the proportional increases with total control most often exceeded the average additive effects of both treatments.

Pine height growth was significantly affected by both woody and herbaceous competition, with the general order of increasing height being: no control < woody control < herb control < total control. Woody control significantly affected height at all locations except Jena (LA) and Counce (TN), while total height was slightly less (3–6% less) after woody control-only treatments at Jena (LA) and Bainbridge (GA). At other locations, pine height increased by 4.5–28% (0.5–3.2 ft) after controlling woody competition only. Herbaceous control significantly increased fifth-year pine heights at all locations (Table 5), and the increases ranged from 18–62% (1.5–7.4 ft). The increase in height with the herbaceous control only treatment depended on the amount of woody competition present at a location.

Following total control treatments, fifth-year pine heights averaged 59% taller than those pines with no control (11.5 vs. 18.2 ft). The prevalence of nonsignificant interactions means that the response in height growth after controlling both woody and herbaceous competition was similar to the sum of the effects of these treatments applied singularly. The significant interactions (greater than additive) at Tallassee (AL) and Camp Hill (AL) are due to the

Table 4. Mean pine density, height, dbh, basal area, and volume index in the fifth year.

	LCP	Middle Coastal Plain						Hilly Coastal Plain			Piedmont		
Vegetation control	Pembroke GA (1)	Bainbridge GA (2)	Liberty MS (3)	Atmore AL (4)	Liverpool LA (5)	Jena LA (6)	Arcadia LA (7)	Tallassee AL (8)	Warren AR (9)	Counce TN (10)	Camp Hill AL (11)	Monticello GA (12)	Appomattox VA (13)
	Density (trees/ac)												
None	533	527	428	530	532	469	523	508	527	535	502	519	491
Woody	522	532	379	505	535	447	517	497	530	532	499	499	425
Herb	521	527	458	472	516	502	502	505	527	516	505	499	445
Total	525	535	450	516	521	510	533	524	519	516	508	505	455
	Height (ft)												
None	11.6	15.1	14.0	10.4	9.7	14.5	9.8	10.3	11.2	10.4	11.1	13.3	8.5
Woody	14.8	14.7	16.0	12.9	11.1	13.7	11.8	11.0	12.6	10.8	11.6	15.7	10.9
Herb	18.8	19.5	21.9	14.0	15.3	20.0	15.5	13.8	17.1	12.3	13.8	17.2	10.0
Total	20.4	22.6	22.7	18.4	17.0	20.6	18.1	17.7	17.6	12.6	18.2	17.7	13.5
	dbh (in.)												
None	1.7	2.5	1.9	1.2	1.1	2.4	1.4	1.3	1.6	1.7	1.5	2.0	0.9
Woody	2.4	2.9	2.7	1.9	1.6	2.2	2.0	1.8	2.0	1.8	1.8	2.6	1.7
Herb	3.2	3.3	3.5	2.0	2.4	3.7	2.6	2.1	3.1	2.2	1.9	3.1	1.3
Total	3.6	4.2	4.4	3.2	3.2	4.0	3.7	3.5	3.3	2.4	3.8	3.3	2.6
	Basal area (ft^2/ac)												
None	10.0	19.7	10.0	5.2	4.7	16.4	6.7	5.6	8.5	8.7	6.9	12.6	2.9
Woody	18.0	25.7	16.1	10.9	8.9	13.4	12.6	9.6	12.9	9.9	10.2	19.7	7.4
Herb	31.1	33.3	32.8	11.5	18.8	39.7	20.9	15.0	28.2	14.9	11.5	27.0	5.2
Total	38.4	53.3	50.6	31.7	31.8	46.2	42.1	36.1	32.1	16.9	41.6	31.7	18.3
	Volume index (ft^3/ac)												
None	105	221	103	56	49	170	72	64	93	105	70	136	31
Woody	191	235	177	118	100	139	140	109	138	114	114	225	80
Herb	363	313	407	131	203	474	247	165	344	187	119	318	51
Total	466	702	671	385	376	559	524	436	400	214	488	381	186

Table 5. Contrast probabilities of greater F-statistics associated with means of fifth-year pine measurements

Vegetation control	LCP	Middle Coastal Plain						Hilly Coastal Plain			Piedmont		
	Pembroke GA (1)	Bainbridge GA (2)	Liberty MS (3)	Atmore AL (4)	Liverpool LA (5)	Jena LA (6)	Arcadia LA (7)	Tallassee AL (8)	Warren AR (9)	Counce TN (10)	Camp Hill AL (11)	Monticello GA (12)	Appomattox VA (13)
	Density												
Woody (W)	0.437	0.230	0.166	0.449	0.541	0.633	0.115	0.588	0.763	0.867	0.990	0.527	0.378
Herb (H)	0.530	0.805	0.026	0.087	0.045	0.007	0.736	0.126	0.549	0.052	0.643	0.527	0.787
W × H	0.146	0.805	0.309	0.020	0.837	0.305	0.034	0.070	0.549	0.867	0.816	0.267	0.226
	Height												
Woody	0.001	0.040	0.004	<0.001	0.035	0.804	0.001	0.001	0.037	0.078	0.003	0.014	0.011
Herb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
W × H	0.125	0.013	0.101	0.149	0.782	0.086	0.566	0.009	0.283	0.894	0.013	0.083	0.430
	dbh												
Woody	<0.001	<0.001	<0.001	<0.001	<0.001	0.801	<0.001	<0.001	0.024	0.035	<0.001	0.015	0.002
Herb	0.001	0.001	<0.001	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W × H	0.123	0.110	0.511	0.038	0.336	0.027	0.057	0.009	0.442	0.781	0.001	0.256	0.062
	Basal Area												
Woody	0.001	<0.001	<0.001	<0.001	0.010	0.357	<0.001	<0.001	0.073	0.036	<0.001	0.052	<0.001
Herb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
W × H	0.831	0.013	0.002	0.064	0.129	0.027	0.001	<0.001	0.911	0.540	<0.001	0.656	0.008
	Volume Index												
Woody	0.009	<0.001	<0.001	<0.001	0.005	0.334	<0.001	<0.001	0.056	0.055	<0.001	0.036	<0.001
Herb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
W × H	0.691	<0.001	0.002	0.605	0.077	0.058	<0.001	<0.001	0.832	0.265	<0.001	0.690	0.013

exceptionally large growth response to total control at sites with both dense woody and herbaceous competition, while at Bainbridge (GA) it was due to the negative response to woody-only control.

Diameter growth showed the same pattern found with height growth, except the proportional response to control was larger (Table 6). All contrasts for both woody and herb control effects were significant, except at Jena (LA). The Jena site showed less diameter growth with woody-only control compared to no control because of an infestation of woolly croton (*Croton capitatus* Michaux.), a large annual forb, that initially became more severe with woody control treatments. Appomattox (VA) differed from other sites with more diameter growth after woody-only control compared to herbaceous-only control, owing to extremely dense arborescent and nonarborescent woody competition and lower levels of herbaceous vegetation than at the other locations (Table 2). Significant interactions were found only on sites having large amounts of hardwoods or nonarborescent shrubs, except for Jena (LA), owing to the woolly croton infestation. Thus, woody and herbaceous control had additive treatment effects on diameter growth at nine sites.

Basal area was increased by 14–155% (1.2–8.0 ft^2/ac) at all locations after woody control treatments (leaving herbaceous competition), except at Jena (LA), where an 18% reduction occurred following woody control. Nonsignificant main effects for woody control were determined not only for Jena, but for Warren (AR) and Monticello (GA), even though 23% and 30% more pine basal area occurred on these two latter sites following woody control treatments. With herbaceous control only, basal area was consistently increased at all sites from 67–300% (2.3–23.3 ft^2/ac). On plots with herbaceous control, pine basal

Table 6. Loblolly pine height, dbh, basal area, and volume index after 5 years for the 13 plantation locations: the overall means and range of values, and the average percent change and percent range when comparing vegetation control relative to no control.[1]

Vegetation control	Height		dbh		BA		Volume index	
	mean	range	mean	range	mean	range	mean	range
	(ft)		(in.)		(ft^2/ac)		(ft^3/ac)	
None	11.5	8.5–15.1	1.6	0.9–2.5	9.1	2.9–19.7	98	31–221
Woody	12.9	10.8–16.0	2.1	1.6–2.9	13.5	7.4–25.7	145	80–235
Herb	16.1	10.0–21.9	2.7	1.3–3.7	22.3	5.2–39.7	255	51–474
Total	18.2	12.6–22.7	3.5	2.4–4.4	36.3	16.9–53.3	445	186–702
	(%)							
Woody only	13	−6–28	34	−8–89	64	−18–155	67	−18–158
Herb only	39	18–62	65	27–118	155	67–300	171	42–314
Total	59	21–85	125	41–191	366	94–577	424	104–667

[1] Average percent values are the means of the 13 percentage values that were each calculated as follows: Percent change = (vegetation control − no control)/no control. The average percent change will not equal a calculated change using the above mean values for height, dbh, BA, or volume index.

area in the fifth year ranged from 5–40 ft^2/ac (Table 4) and hardwood basal area from 1–17 ft^2/ac (Table 2). Only at Tallassee (AL), Camp Hill (AL), and Appomattox (VA) did the average hardwood basal area exceed that of pine after herbaceous control. At no location did the combined pine-hardwood basal area following herbaceous control only exceed that of the pine basal area with total control, suggesting that thus far pine alone was more productive than mixed stands when considering only woody vegetation. Total control yielded pine basal areas greater than four times over the no-control treatments at 6 of the 13 locations—increases ranged from 94–577% (8.2–40.6 ft^2/ac). At eight locations, total control significantly increased pine basal area more than the summed increases from controlling either the woody or the herbaceous components alone (Table 5).

When density, height, and diameters (GLD, D6, and dbh) were combined into a volume index at age 5, there was an average volume increase of 67% (47 ft^3/ac) for woody control only, 171% (157 ft^3/ac) for herbaceous control only, and 424% (347 ft^3/ac) for total control (Table 6). Increased volume growth ranged from 104–667% with total control—an indication of the potential early gains that are possible with competition control. Significant volume increases with woody control—the component traditionally targeted—only occurred at sites with greater than 1 ft^2/ac of arborescent competition and/or greater than 2500 rootstocks/ac of nonarborescent woody competition in the fifth year.

To further examine the influence of hardwood competition on pine volume growth, the variation in soil-site differences among locations was minimized by scaling volume on the herb-control only treatments by the response on the total-control treatments. Pine volume growth with no competition should be one of the best indicators of site. Figure 3a presents the relationship between hardwood (arborescent) basal area on the herb-control treatment and percent pine volume reduction calculated as follows: [pine volume index (pvi) with total control–pvi with herb control]/pvi with total control. This figure shows the variation in arborescent competition among sites, while the regression suggests a fairly strong relation (R^2 = 0.70) between arborescent basal area and pine volume growth reduction. The greater than expected (fitted) reduction in pine volume growth for Atmore (AL) (Loc. 4), Camp Hill (AL) (Loc. 11), and Appomattox (VA) (Loc. 13) is likely due to the high levels of nonarborescent woody competition that are not quantified in Figure 3a.

Figure 3b shows the relationship between the 5-year average herbaceous cover and the percent pine volume reduction that was calculated using the woody control only values as above. Linearity of this relation has been previously reported (Nelson et al. 1981, Knowe et al. 1985). Obviously, some of the variation is inherent from having different estimators at each location, but still a significant 49% of the variation in pine volume reduction can be attributed to a mean estimate of herbaceous cover over the first 5 years.

The fifth-year treatment averages for pine height, dbh, basal area, and volume index are presented with the averages for the first 4 years in Figure 4. These figures show similar trends with each of the pine variables, with only a few notable exceptions. For all pine variables, the curves for total-control and no-control treatments are still diverging after 5 years. The average height growth re-

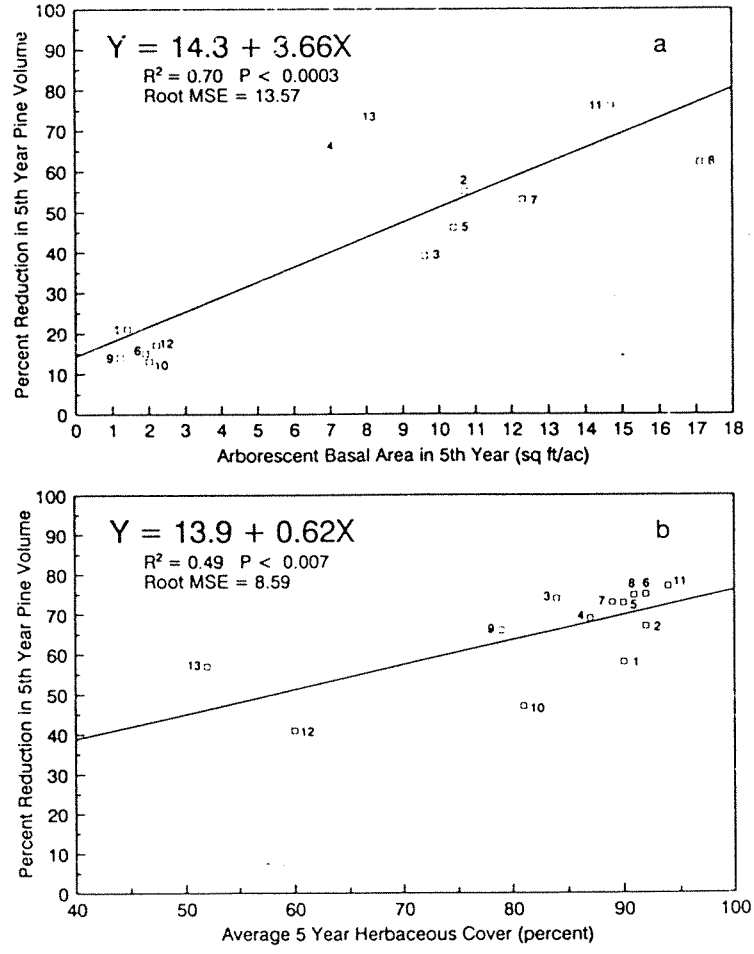

Figure 3. Relationships across the 13 locations between percent reduction in pine volume relative to volume growth without competition and: (a) arborescent basal area in the fifth year, and (b) average herbaceous cover in September for the first 5 years. Location numbers are shown.

sponse to total control, and to a lesser extent with herb control, has slowed between the fourth and fifth years, which is not yet apparent with diameter. It is apparent that with these average curves that divergence is increasing between woody control and herbaceous control curves and the no-control treatments, and it is more pronounced with woody control.

The relationship between woody-control and herb-control treatments is further examined in Figure 5 with data from four locations having the highest densities of hardwoods. The annual differences in mean-tree basal area at groundline between herb-control-only and woody-control-only treatments appear to be diminishing over time, specifically starting in the fifth year. This suggests an increasing influence of woody plants on pine growth coincidental with a decreasing influence of herbaceous plants.

Comparisons with other Research

The growth increases on COMP locations as percentages are very similar or exceed previously reported responses. For the herbaceous control studies reported by Creighton et al. (1987), on the four loblolly locations with fifth-year results, heights after 2 years of control were increased by 41% and diameters by 67%, the same percentages as for COMP averages when comparing the difference between total control and woody control only. Glover et al. (1989), reporting on 4–5 years of total control vs. woody-only control at three locations in the Southeast, found an average fifth-year volume increase of 192% compared to 207% on COMP locations. With complete woody control in Louisiana (Cain and Mann 1980), fifth-year increases in height were 9% compared to a 12% COMP average, diameter was 27% compared to a 31% COMP average, and volume was 58% compared to a 48% COMP average.

Considerable question remains regarding the long-term gains that will be derived from early-growth enhancement using vegetation control. Several investigations are now older than 10 years and give some indication of the possible outcomes. Tiarks and Haywood (1986) gave fifth-year results from a similar study to the one reported here on a root-raked site near Sikes (LA) where hoeing was used for 4 years to control herbaceous weeds around loblolly pines, complete woody control treatments were included, and their combination. The volume growth reported by Haywood and Tiarks (1990) at age 11 indicates that absolute volume increases reported at age 5 had maintained or were still increasing, with 520 ft^3/ac (outside bark) more volume with herb control and 450 ft^3/ac more volume with woody control.

On less intensively prepared sites, annual woody control from 2–10 years in three loblolly pine plantations in northern Louisiana resulted in a consistent 50–57% increase in tree volumes that lasted from age 5 to 10 (Cain and Mann 1980, Haywood 1986). Clason (1989) also studying loblolly pine in northern Louisiana reported that an absolute gain of 500 ft^3/ac at age 10 following total competition control was maintained through age 20, and by repeated thinnings to age 30. Likewise, 12-year results from the study reported by Glover et al. (1989), still showed diverging volume curves compared to checks at two of the three study locations when pre-commercial thinnings were used to manage stocking. Thus, volume growth enhancement with competition control can be maintained up to 20 years on some sites, and may be maintained further with stocking control through thinnings. It should be acknowledged that the growth gains with opera-

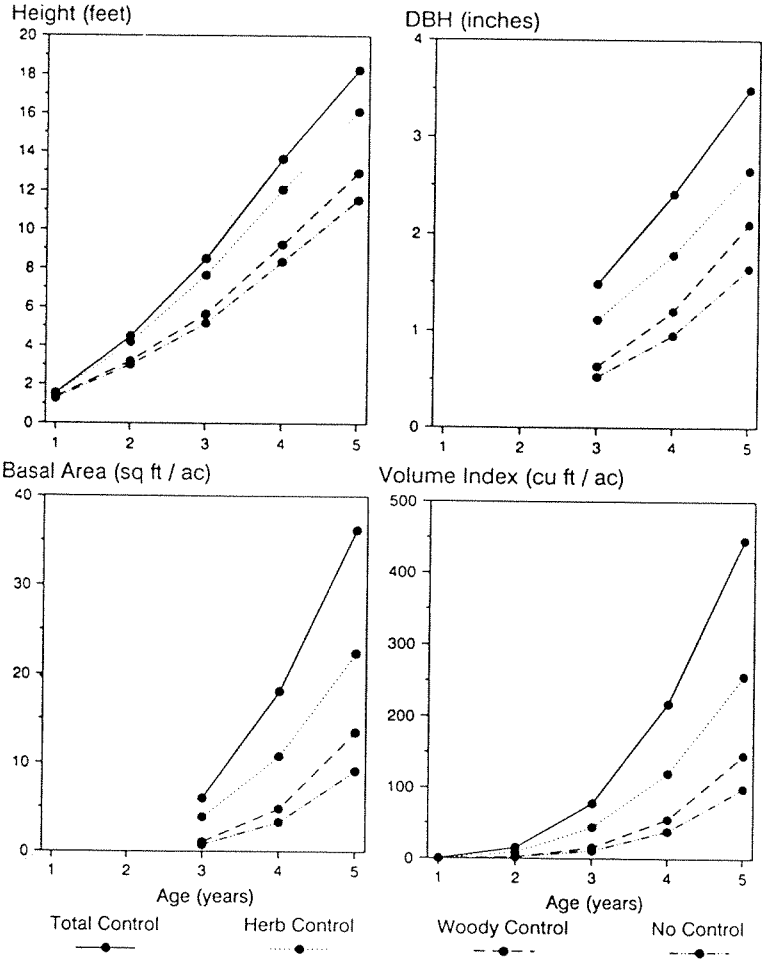

Figure 4. Mean height, dbh, basal area, and volume index of loblolly pine for the 13 COMP plantation locations for the first 5 years.

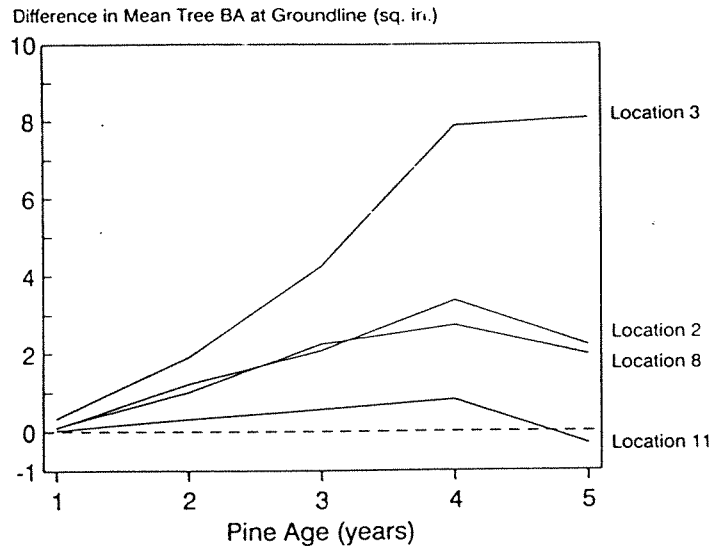

Figure 5. Differences in mean basal area (GLD) of individual trees between herb-only and woody-only control treatments over the first 5 years for the four locations with the highest levels of woody competition.

tional treatments that provide partial or temporary control may be decidedly less than those measured on these experimental plots where absolute component control was achieved.

As far as the long-term influence of arborescent competition on pine yields, a developing hypothesis has been incorporated in a growth and yield model by Burkhart and Sprinz (1984). This hypothesis is based on the observed constancy in the proportion of hardwood to pine basal area from age 11 to 24 on a long-term study in Alabama (Glover and Dickens 1985). This proposes that once hardwoods are established in a pine stand, pines do not "outgrow" and dominate the hardwoods, but rather they remain as a competitive component. Codominant and dominant hardwoods also displace a greater proportion of loblolly pine volume in mixed stands than the proportion of hardwood to pine basal area would indicate (Glover and Dickens 1985, Langdon and Trousdell 1974). For example, a 20% hardwood basal area reduced pine volume by 50% in 24-year-old stands in Alabama, which suggests that the common decurrent growth of most hardwood canopies and root systems preempt more area and/or resources than an equal amount of pine basal area growing in the typical excurrent habit. Thus, arborescent competitors that appear early in a stand will continue to subtract a disproportionate amount of pine volume growth as the stand matures.

SUMMARY

These results show that herbaceous and woody competition affect both height and diameter growth of loblolly pine during the first 5 years over most of its range. During this period, diameters are reduced proportionally more than heights by competition, which suggests that studies of competition influences should measure stem diameters (GLD and/or dbh), as well as heights, to assess response. An estimate of volume growth that combines diameter, height, and survival is the best integrated response variable for judging competition influences and control treatment effectiveness.

On all but one COMP location, herbaceous competition reduced pine volume more than woody competition during the first 5 year; however, the influence of woody competition is increasing on sites with high hardwood densities. Total competition control yielded phenomenal volume growth increases of twice up to 6.6 times that measured on no-control checks and was greater than the additive effects of herbaceous or woody control on 7 of the 13 locations. This suggests that control of either component should increase early loblolly pine growth, but the control of both can at times result in even greater gains. A review of longer term studies suggest that growth gains from early competition control are maintained until at least midrotation.

The growth response of loblolly pine at these 13 locations can be used to judge and report competition control studies in a way that permits a wider comparison of results. □

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